CIRP – SMS Steering Model Workshop

ADCIRC – Overview and Model Features

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ADCIRC Overview

- Forecast water surface elevations and currents in coastal oceans, estuaries, lakes and rivers

- Specifically solve for “long wave” circulation which assumes that horizontal scales of motion are greater than the vertical scales of motion

- Applications
  - Coastal inundation due to tides and hurricanes
  - Navigation
  - Sediment movement
  - Pollutant transport
  - Fisheries

ADCIRC Overview

- ADCIRC is a highly developed state-of-the-art computer program for solving the equations of motion for a moving fluid on a rotating earth
- ADCIRC can be run either as a two-dimensional depth integrated (2DDI) model or as a three-dimensional (3D) model
- In either case, elevation is obtained from the solution of the depth-integrated continuity equation in Generalized Wave-Continuity Equation (GWCE) form. Velocity is obtained from the solution of either the 2DDI or 3D momentum equations
- ADCIRC can be run using either a Cartesian or a spherical coordinate system

2DDI Governing Equations

- Formulate conservation of mass and momentum to describe the physics.
- Continuity equation

$$\frac{\partial \varsigma}{\partial t} + \frac{1}{R\cos\phi}\left(\frac{\partial UH}{\partial \lambda} + \frac{\partial VH\cos\phi}{\partial \phi}\right) = 0$$

- The momentum equations have been formulated using the traditional hydrostatic pressure and Boussinesq approximations

2DDI Governing Equations

- Conservation of momentum equations

$$\frac{\partial UH}{\partial t}+\frac{1}{R\cos\phi}\left(\frac{\partial UUH}{\partial\lambda}+\frac{\partial UVH\cos\phi}{\partial\phi}\right)-\left(\frac{U\tan\phi}{R}+f\right)VH=$$

$$-\frac{H}{R\cos\phi}\frac{\partial}{\partial\lambda}\left[\frac{p_s}{\rho_0}+g(\varsigma-\alpha\eta)\right]+M_\lambda+D_\lambda+\frac{\tau_{s\lambda}}{\rho_0}-\frac{\tau_{b\lambda}}{\rho_0}$$

$$\frac{\partial VH}{\partial t}+\frac{1}{R\cos\phi}\left(\frac{\partial VUH}{\partial\lambda}+\frac{\partial VVH\cos\phi}{\partial\phi}\right)-\left(\frac{U\tan\phi}{R}+f\right)UH=$$

$$-\frac{H}{R}\frac{\partial}{\partial\phi}\left[\frac{p_s}{\rho_0}+g(\varsigma-\alpha\eta)\right]+M_\phi+D_\phi+\frac{\tau_{s\phi}}{\rho_0}-\frac{\tau_{b\phi}}{\rho_0}$$

2DDI Governing Equations

- Basic equations established by Laplace in 1775
- Cannot solve analytically for most problems of engineering interest
- Numerical Solutions $\rightarrow$ Convert partial differential equations to algebraic equations at discrete points
  - 1970 $\rightarrow$ first numerical solutions $\rightarrow$ 50 discrete points
  - 1980 $\rightarrow$ 250 discrete points
  - 2000 $\rightarrow$ 1,000,000 discrete points

ADCIRC Forcing Features

- ADCIRC accommodates the following body forces
  - Gravity
  - Tidal potential
  - Earth load/self attraction tide

- ADCIRC can be forced on the boundaries using
  - Elevation boundary condition
  - Normal flow boundary conditions
  - Surface stress boundary conditions
  - Atmospheric pressure

ADCIRC Forcing Features

- ADCIRC boundary conditions include:
  - Specified elevation (harmonic tidal constituents or time series)
  - Specified normal flow (harmonic tidal constituents or time series)
  - Zero normal flow
  - Slip or no slip conditions for velocity
  - External barrier overflow out of the domain
  - Internal barrier overflow between sections of the domain
  - Surface stress (wind and/or wave radiation stress)
  - Atmospheric pressure
  - Outward radiation of waves (Sommerfeld condition)

ADCIRC Features

- Cartesian or spherical coordinates
- 2DDI/3D (stress or velocity based)
- Nonlinear or linear
- Modularity, Options Toggle On/Toggle Off via Input File
- Full wetting/drying elements
- Barrier elements (e.g. levees)
- Conduits and porous barriers
- Harmonic analysis (“on the fly”)
- Cold or hot starts
- Well Documented, Web Served, HTML Users Manual

ADCIRC Solution Strategy

- Apply GWCE based reformulation of the governing equations prior to any numerical discretization

- GWCE = Generalized Wave Continuity Equation
  - Manipulation of governing Shallow Water Equations (SWE)
  - Contains numerical parameter τ_0 which chooses balance between the primitive continuity and the wave continuity equations

ADCIRC Solution Strategy

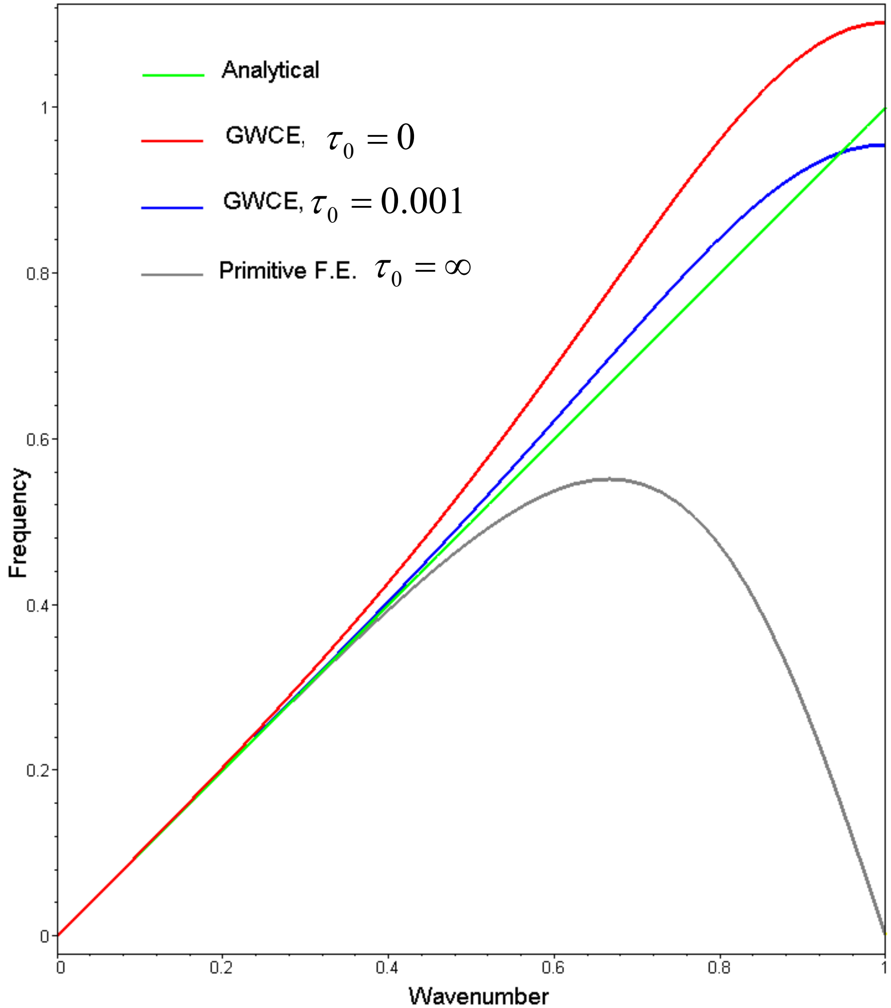
- Generalized Wave Continuity Equation

$$GWCE \equiv \frac{\partial}{\partial t}\left(PCE\right) - \nabla \cdot \left(CME\right) + \tau_0 \left(PCE\right) = 0$$

- The full primitive solution leads to a folded dispersion curve
  - Low wavenumber (long wave) physical wave
  - High wavenumber (short wave) spurious wave (noise)

- The use of the GWCE instead of the primitive continuity equation solved in conjunction with the momentum equations, yields a monotonic dispersion curve
  - Only a low wavenumber (long wave) physical wave
  - Monotonic dispersion relationship prevents generation of spurious oscillations

GWCE Parameter Selection



ADCIRC Solution Strategy

- Parameter Ranges
  - $\tau_0 = 0 \rightarrow$ Pure Wave Equation
  - τ_0 = infinity $\rightarrow$ Primitive Equation

- Effect of parameter selection
  - τ_0 too low $\rightarrow$ Poor local mass conservation
  - τ_0 too high $\rightarrow$ Folded dispersion curve $\bumpeq$ spurious modes

- Correct selection of τ_0 ***range*** is related to the local frictional balance

ADCIRC Solution Strategy

- Accurate solutions require discrete points to be closely spaced where the solution varies rapidly
- ADCIRC’s Finite Element based solution strategy allows for a very large numbers of discrete points to be placed in a highly flexible unstructured manner
  - Provide localized refinement to the degree required improving accuracy while minimizing computational cost
  - Allows the definition of large domains to simplify the specification of boundary conditions and to improve the accuracy of the results due to improved exchange processes

ADCIRC Domain/Grid Design

- ADCIRC is designed for a Large Domain / Locally Refined Grid Strategy
- Large Domains with open ocean boundaries in the deep ocean greatly simplify the task of boundary condition specification
  - Response in deep waters is significantly simpler than on the shelf and therefore simpler to specify as a boundary condition
  - Any errors in providing dynamically correct boundary conditions are more readily absorbed in the computation
  - Nested grid problems in terms of correct dynamic coupling and b.c. discretization accuracy are also avoided

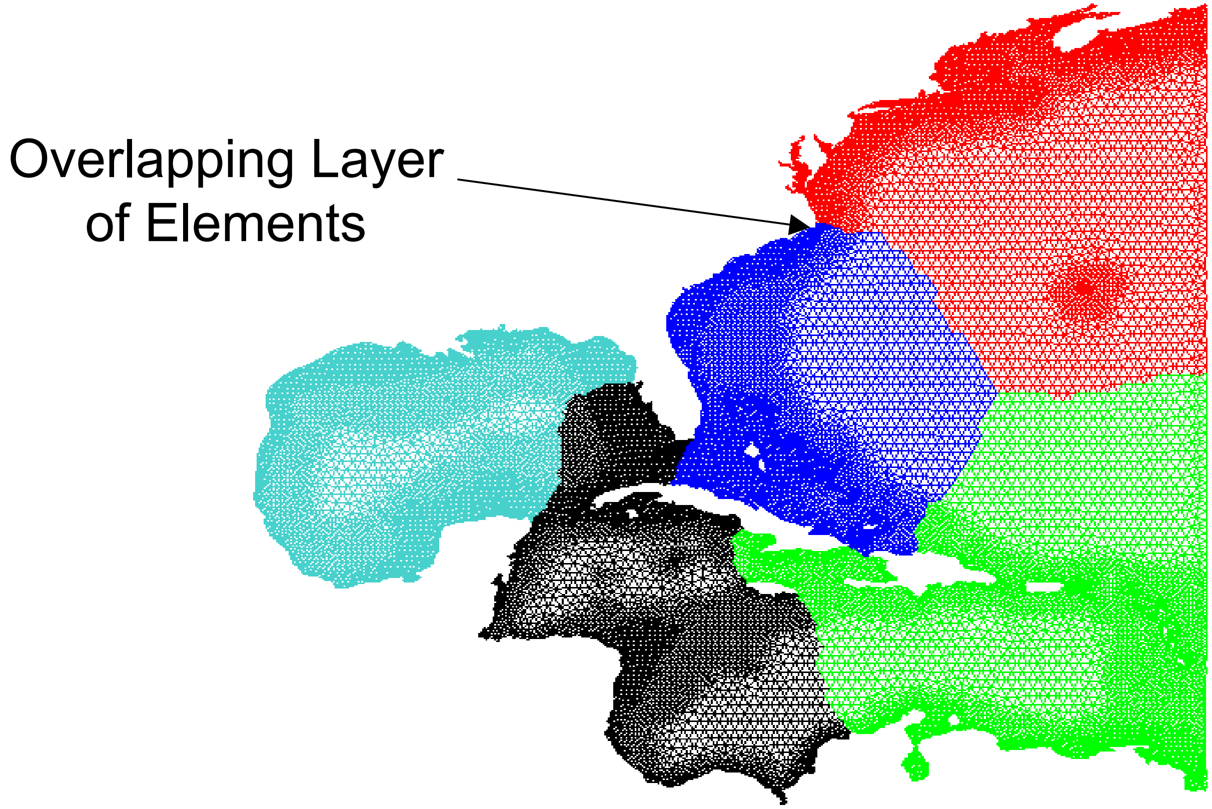
ADCIRC Domain/Grid Design

- Grid Resolution should be provided where response gradients are high
  - Coarse grids in the deep ocean
  - Refined grids on the continental shelf
  - Highly refined grids in inlets, estuaries, rivers, canals and flood prone overland regions

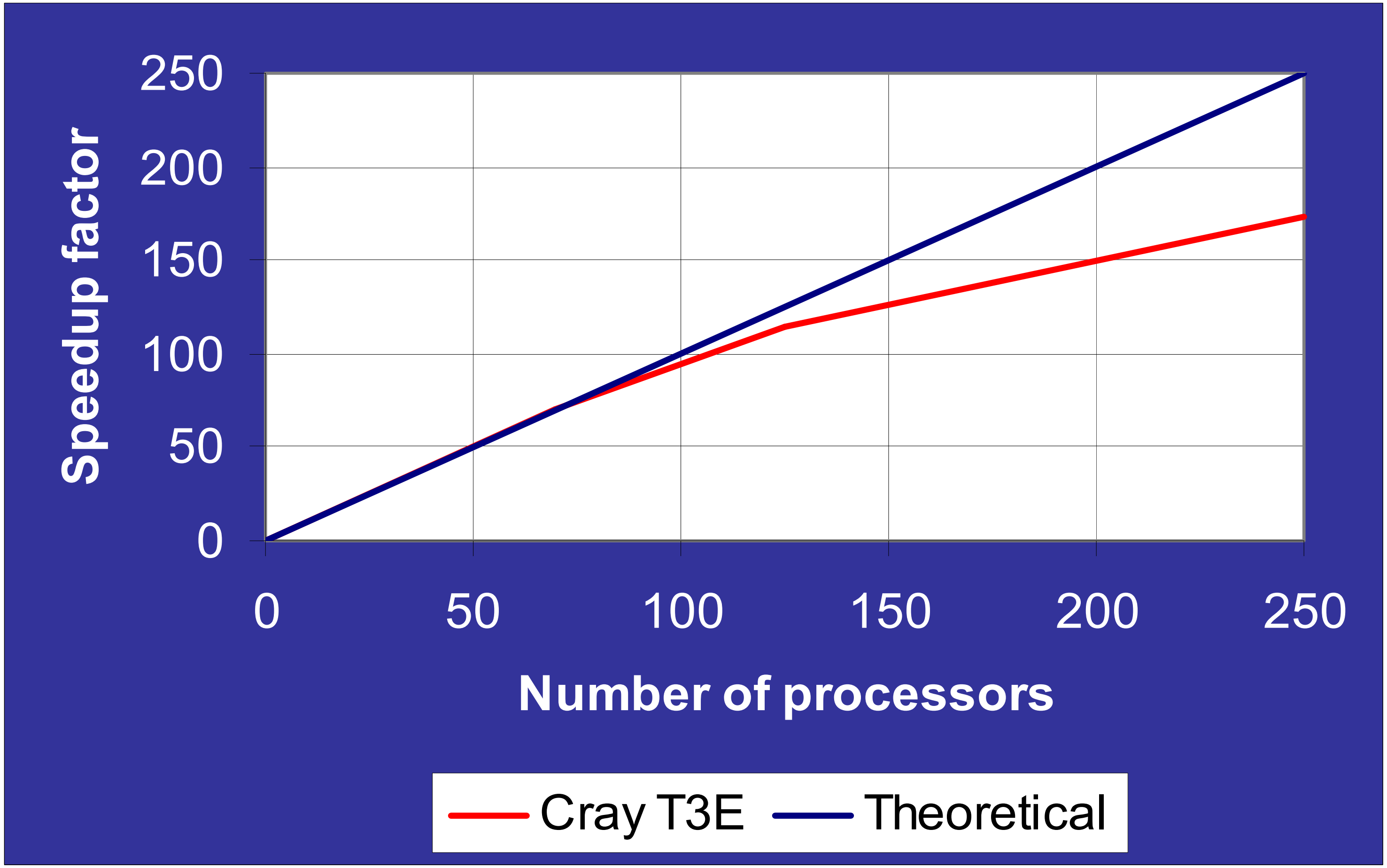
Computational Efficiency

- Highly Efficient Code → very large domains are possible
- Loop-level Optimization
- Temporal – Fully Implicit Time Marching available
- ADCIRC is available in single thread and parallel versions that yield the same answers to machine precision
- Spatial – Parallel Computing
  - Domain Decomposition
  - Distributed Memory
  - MPI based communication

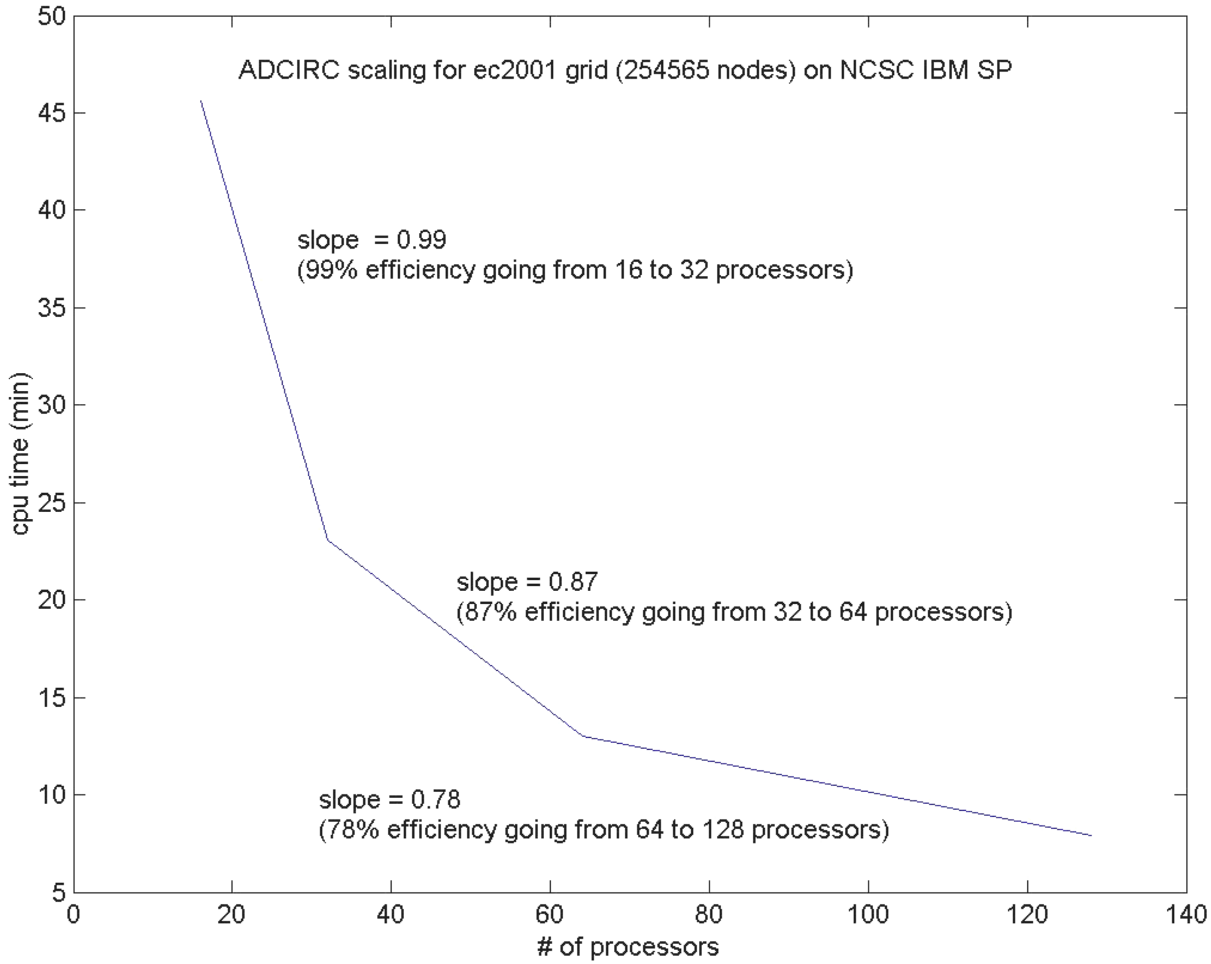
ADCIRC – Domain Decomposition



Parallel Efficiency – Cray T3E



Parallel Efficiency – IBM SP



ADCIRC Development

- DG algorithm development
  - Discontinuous Galerkin (DG) for Hydrodynamics, Transport and Sediment Transport is under intensive development
  - DG will be fully incorporated as an option in ADCIRC
  - Beta versions will be available by the end of this FY

- DG Properties
  - DG in its simplest form is very similar to Finite Volume on an unstructured variably spaced grid
  - DG is elementally mass conserving
  - DG is very robust in its lowest order implementation
  - p and h refinement are being implemented
  - Local nonconforming grid refinement is possible on the fly

ADCIRC Development

- Multi-algorithmic implementation is under development
  - ADCIRC will work simultaneously with DG and GWCE based CG algorithm
  - Optimal algorithm will be selected for appropriate portions of the domain
  - Not one algorithm is optimal for all hydrodynamic problems ♎ Use the best algorithm for the local flow

ADCIRC Development

- 3D Model Development
  - Experience base with 3D barotropic is developing
  - Testing 3D diagnostic baroclinic – pressure gradient in level coordinates, rest in stretched sigma coordinates
  - 3D wave/current interaction
  - 3D prognostic baroclinic (in parallel)

- Data Assimilation
  - TRUXTON inverter
  - IOM – NSF ITR

Summary

- ADCIRC – sophisticated, robust hydrodynamic model with many options
- Continuously advanced with new
  - Basic algorithms
  - Computing paradigms
  - Physics
  - Features
- Well-positioned to simulate a wide-variety of hydrodynamic problems
- For more information, see the ADCIRC web site:

  www.marine.unc.edu/C_CATS/adcirc